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G.W.398

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AD No. 103433

ROYAL AIRCRAFT ESTABLISHMENT

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A STUDY OF THE STRUCTURE WEIGHT OF BALLISTIC MISSILES

by

N.E.WILD and H.R.ULRICH

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ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

A Study of the Structure Weight of Ballistic Missiles

by

N. E. Wild and H. R. Ulrich

SUMMARY

This Note, which is an extension of an earlier study, discusses the structural weight of ballistic missiles and its influence on range.

Because of their straightforward design, only missiles with a single propulsion stage using one, two or three rocket motors are considered. All have separable stages for re-entry but the following variations in the design of the first stage are considered.

(a) most of the layouts are conical in shape, but two layouts are basically cylindrical in shape;

(b) take-off acceleration is varied between 0 and 0.5g;

(c) the weight of the re-entry stage to be carried is varied between 4,000 and 10,000 lb.

A stainless steel of high weldable strength is assumed throughout, but the influence of steels of inferior quality is shown.

Weight breakdowns and ranges for butt-welded missiles of nominal sheet thickness (the same thickness material is used for all the tank walls) are given, and compared with those of missiles revised for overlap welding, allowance for sheet tolerances, and motor units of an increased weight. The penalty for including these additional weights is a 10 to 15% reduction in range.

Three 2-motor missiles with the favoured take-off acceleration of 0.3g, carrying heads of varying weight and with low, medium and high drag configurations are singled out for a more detailed weight and range examination. Because of the increased ease of transportability as compared with the conical missile, two of the missiles are of cylindrical shape and of different fineness ratios. The reductions in range, divided into weight and drag losses, are given.

This study is still incomplete, and further work will have to be carried out covering such variables as tank fineness ratio, relative weight of tank pressurisation system, the use of fins for stabilisation, etc. The amount of residual propellants has also to be determined with greater confidence.

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1 Introduction

This Note reports the progress in assessing the likely structure weight and performance of medium range ballistic missiles. A preliminary study (Ref. 1) showed that a single stage of propulsion is feasible for the ranges considered, provided a simple thin-skinned structure could be used for the tank section. Further studies extending the investigation to various sizes and shapes of missile have been made, and a summary of the main parts is reported here. These studies fall naturally into two parts:

(a) the first part follows a decision to use an existing motor developed by North American Aviation Inc. in U.S.A., and covers missiles of various sizes powered by one, two or three of these motors.

(b) the work in (a) above leads to the conclusion that the operational requirement could be met satisfactorily with a missile powered by two motors operating together in a single stage, and that the acceleration at take-off should not be less than 0.3g. Further studies were then limited to variations of designs around this particular type of missile layout.

These two parts of the investigation are discussed separately below.

2 General Considerations

2.1 Description

The ballistic missiles considered in this Note consist of two parts, the first stage (with motor, propellants, tanks, etc.) and the head, or re-entry stage. The head containing the payload is separated from the first stage after final fuel cut-off and coasts to the target. As it is not possible to define finally the size, shape or weight of the head at present, this Note considers only the design of the body of the first stage suitable for a number of different head weights.

The first stage is made up of two tanks in tandem, a stabilising skirt, rocket motor units and guidance and control equipment (see Fig. 3). The front tank carries liquid oxygen, the rear tank kerosene. Fixed to the rear end of the tank section is the stabilising skirt shrouding the rocket motor units and the guidance and control assemblies. In some of the missiles described in detail later on the guidance equipment is housed in a special guidance chamber situated at the front end of the tank section (see Fig. 7). The weight of the guidance equipment is estimated to be 500 lb, and assumed constant over the whole range of missiles investigated. The weight of the control gear depends on the number of motors, and is estimated to be 400 lb, 600 lb and 800 lb for one, two and three motors. For the first part of this study the dry weight per motor unit has been taken as 1,260 lb, but as information received in the course of this investigation indicates an increase in weight, 1,860 lb has been assumed for the later designs.

To keep the weight of the first stage low, a tank made up of a single skin has been adopted; this skin thickness being kept constant for all the tank walls of a given missile. To enable this structure to support the head, oxidant, fuel, etc. both tanks are pressurised to 40 lb/sq in. This pressure not only stabilizes the tank shell but in conjunction with the inertia head of the fuel provides the necessary pressure at the pump inlets. The effect of changing this pressure has not yet been investigated fully. It has been assumed that the motor thrust can be reduced towards the end of the flight so that the acceleration of the missile does not exceed 10g.

2.2 Sheet Material for the First Stage

Any material considered as skin for the tanks has to satisfy three main requirements:

(i) small loss of strength at elevated temperatures;

(ii) good weldability (riveted tanks are not considered practical);

(iii) good corrosion resistance, so as to achieve very long life on operational sites.

It has been estimated that during ascent on a particular trajectory the skin temperature of the tanks will very likely rise to about 300°C. At this temperature the use of aluminium alloys is not practicable. A further reason for their exclusion is the difficulty with joints either due to doubtful welding properties of the high strength alloys or the doubtful properties of adhesive under the environmental conditions involved. Stainless steel sheeting was chosen for the tanks section of all missiles as it is the material nearest to fulfilling all the three requirements mentioned whilst still being relatively inexpensive and available.

Certain high strength titanium alloys are at present being investigated, and, because of their high strength/weight ratios, may prove to be a weight saving alternative, when they are available.

2.3 Stress Assumptions

An as yet unspecified stainless steel of an ultimate tensile strength of 65 tons/sq in. (based on the plain sheet thickness) in the joints after welding has been assumed for the tanks. The stress calculations were based on a safety factor of 1.5 on the ultimate, allowing a maximum design stress of 43 tons/sq in. The actual thickness of the sheet has been taken to be the nearest gauge above the calculated value. For reasons of easier construction and handling no sheets thinner than 0.032 in. have been used.

Butt-welded joints, and nominal sheet thickness were assumed for the first set of missiles, representing the lightest design possible.

Later tank structures were made of steel sheets joined by welded overlaps. A mean tolerance of 0.003 in. has also been added to their nominal thickness, which is constant for a given tank.

The tanks have been stressed for hoop strength only, taking skin stabilizing pressure and fuel inertia load into account. The lateral forces imposed will depend on the trajectory chosen, on the guidance system, and on the lateral winds. The additional stresses due to the expected order of lateral accelerations i.e. about $\frac{1}{2}$g initially and building up to about 2g as the tanks empty, are quite small compared with the longitudinal stresses due to pressurisation; this conclusion will need much more careful checking when the effects of reduced pressurisation are examined.

Front, partition and base closures are elliptically shaped domes of an axis ratio 2:1. They were stressed by using the general formula for hollow spheres subjected to internal pressure corrected by a factor to allow for the axis ratio.

For all missiles considered the position of maximum stress is in the outer tank wall at the base of the liquid oxygen tank; this mainly arises from the use of constant gauge sheets for the whole of the tank walls.

Failure to limit the maximum acceleration to 10g is unlikely to increase the stress at this point significantly and is unlikely to cause more severe stresses elsewhere within the possible range.

The stabilizing skirt can be riveted, and an aluminium alloy of 17 tons/in.^{2} was found suitable. Though actual calculations have not been made of the temperature sustained by this skirt, it is expected to be below that at which severe loss of strength of the aluminium alloy occurs, both due to the high heat capacity of the thick alloy skin and the position of the skirt being far back along the body; the expected temperature and stressing of this section will need more careful checking in the final designs when the angle of the skirt and other parameters are more accurately known.

3 Survey of Missiles with One, Two or Three Engines

3.1 Original Estimates with High Grade Steel Sheet and Light Construction

The results described in this paragraph represent a direct extention of the work reported in Ref. 1 to a wider range of missile designs, but all using a given N.A.A. engine of 132,000 lb thrust (the S.3). The parameters of the various designs were as follows:

(a) The first stages of all the missiles were conical, with a stabilizing skirt in the rear achieving something like neutral static stability for a mean condition of flight.

(b) The base diameter of the head or re-entry stage was taken as 6 feet.

(c) The head or re-entry stage weight was varied between 4,000 and 10,000 lb.

(d) The thrust-weight ratio at take-off was varied between 1.0 and 1.5, i.e. initial accelerations varied from zero to 0.5g.

(e) The designs were all based on the N.A.A. engine (the S.3) giving an assumed value of thrust at that time of 132,000 lb with a total specific impulse of 245 seconds (including turbine losses), using liquid oxygen and kerosene as the propellants. The dry weight of the motor was assumed to be 1,260 lb[4]. One, two or three of these engines were used in the various designs, the ranges covered being as below:

No. of Motors	Initial thrust-weight ratio	Head weight
1	1.0	5,000 lb
	1.2	5,000 lb
	1.5	5,000 lb
	1.2	7,000 lb
2	1.1	7,000 lb
	1.2	7,000 lb
3	1.0	7,000 lb
	1.2	7,000 lb
	1.5	7,000 lb

3.11 Structural Weight Estimates

For all these designs the lightest form of welded tank construction was used, employing butt-welded sheets.

A selection of the results of the weight assessment of these designs is given in Table I, and all results are summarised in Fig. 1 and 2, together with a few designs outside this series. An examination of these results show that the weight of the structure is determined principally by its size, and that the initial acceleration and the head weight have relatively little effect. The weight of the main components is plotted against tank capacity in Fig. 1, showing that most of the weight is in the tank itself. The scatter of the points is largely caused by using nominal sheet thicknesses. The smooth curve is considered satisfactory for this survey, ignoring the fact that the weight will increase in steps, if standard gauges of metal are used.

In Fig. 2 the weights are expressed as a proportion of the tank contents. It is seen that this proportion is fairly constant being about $2\frac{1}{2}$ per cent of the weight of structure plus propellants. For the smaller missiles this figure is somewhat higher as is to be expected on dimensional grounds. Fig. 2 was used to estimate the weights of missiles intermediate to those examined in detail when deriving the performance plots discussed in the next paragraph. From these performance curves 0.3g was chosen as the most favoured take-off acceleration. Further studies were then made at this figure for one, two and three motors with a head of 7,000 lb. The dimensions of these new missiles are shown in Fig. 3 and their weight breakdown given in Table II. The results agree very well with the original interpolation from Fig. 2, the structure weight factors, τ, being 0.0255, 0.0243 and 0.0237.

3.12 Comparative Range Estimation

Using the structure weight determined as described in para. 3.11 the range performance of the various missiles has been evaluated making the following assumptions about the trajectory:

(a) The missile climbs vertically to 1,000 feet.

(b) At 1,000 feet the missile makes an instantaneous turn, and thereafter maintains constant attitude. This constant attitude was chosen so that the angle of the flight path at final fuel cut-off is that giving maximum range. This angle and the range corresponding to the final velocity were taken from Ref. 2.

(c) The constant attitude flight was maintained with full thrust until the acceleration reached 10g, thereafter the same attitude was maintained and the thrust progressively reduced keeping the acceleration at 10g until fuel was cut off.

(d) At the point when fuel was cut off it was assumed that, due to unusable fuel in pipes, motors, etc. and with an allowance for mixture control inaccuracies, a total of 1 per cent. of the propellant weight at take-off remained in the missile.

(e) A mean specific impulse was evaluated and used over each part of the trajectory.

(f) A reduction of 2 per cent was made in the nominal specific impulse to allow for the effect of drag; this figure corresponds to a missile of low drag, i.e. with a mean SC_D/m_0 of about 10^{-4} sq ft/lb.

Checks between ranges calculated by this simple approach and those obtained from the more accurate methods of Ref. 3 demonstrated that the simple method was giving reasonably accurate results; the comparisons made between various missiles using the simple method should be more accurate. No account has been taken of a belief that the optimum trajectory will change for varying values of take-off acceleration. It is not thought worthwhile to tackle this aspect more rigorously until the final layout of the Blue Streak is settled together with the shape of the re-entry stage thus allowing a more accurate estimate of the missile drag and weight.

The plots of Fig. 4 show the comparative ranges of one, two and three engined missiles with varying re-entry stage weight and take-off acceleration; it is obvious that the effect of variation in weights of the missile body, such as increased structure, engine, residual fuel or equipment weights from those assumed or calculated in this Note can be found by adding these changes in weight to the nominal re-entry stage weight and observing the corresponding change in range.

The curves of Fig. 4 suggest that the maximum range will be achieved when the take-off acceleration is as low as 0.1g, but that very little loss in range arises from an increase in the take-off acceleration up to 0.3g. It is considered that the initial design must be based on a figure with nominally too high an acceleration so that adverse changes in A.U.W. during design move the take-off acceleration towards the optimum rather than towards zero take-off acceleration. Studies of the aerodynamic and control problems also influence the choice of take-off acceleration. With a low acceleration the peak aerodynamic pressure is lower, reducing the destabilizing moments and easing the control problem, and, in addition, the aerodynamic heating during the ascent will be lower. It is also considered that control during the initial launch will be more difficult, and interference with surrounding launching structure more likely if too low an acceleration is selected. A figure of 0.3g has, therefore, been assumed as the practical figure for design study purposes.

3.2 The Effect of Steel Sheet with Reduced Strength on the Missile Range

The designs described above have all used a high tensile steel for the structure of the tanks. An ultimate tensile strength of 65 tons/sq in. has been assumed for design purposes. The effect of using lower strength steels was evaluated, to determine the importance of this factor. The three designs of Fig. 3 (and Table II) were re-assessed using a number of different qualities of steel down to an U.T.S. of 35 tons/sq in., and the corresponding performance interpolated from Fig. 4.

The results, in Fig. 5, show the loss in range which is to be expected from the use of lower quality steels for the tank structure. It is seen that the quality of material is more critical at the longer ranges than at the shorter ranges. Thus with one motor a change from 65 tons/sq in. to 45 tons/sq in. for the U.T.S. of the material reduces the range by about 110 miles, or 8 per cent. The three motor version with a range of 2,600 miles will lose nearly 300 miles of range (nearly 12 per cent).

3.3 Revised Structure Weights Including the Effect of Overlapping Joints and Tolerances

Following the results of the original investigation reported in para. 3.1 and para. 3.2 a new study was made of structures using a less ideal tank as regards jointing and sheet tolerance. The opportunity was also taken to include a few corrections as, for instance, a revised, more pessimistic figure for motor weight. The tanks of the first stage treated in

the previous section were constructed of butt-welded steel sheets of nominal gauge thickness. Fusion welded butt joints of high strength stainless steels are in general of somewhat poor efficiency and may not come up to the required 65 tons/sq in. As an alternative, resistance welded lap and butt-strap joints were considered, having one or two seam welds to keep the vessel pressure-tight, and an arrangement of staggered spot welds to take the circumferential and longitudinal tension forces. The sheets overlap by 3 inches in circumferential direction, and were joined longitudinally by butt-straps 6 inches wide. According to standard specifications stainless steel sheets are allowed a unilateral tolerance of +0.005 in. A mean tolerance of +0.003 in. was, therefore, included in the weight of the structure. There may be no need to accept such large percentage tolerances on the sheets if special arrangements are made.

A further weight increase of about 600 lb has been notified for the rocket motors above that reported in Ref. 4, bringing the dry weight per motor unit up to 1,860 lb*.

Table III shows the increase of weight for three different one-motor missiles and two different two-motor missiles due to overlaps, tolerances and heavier motors. Overlapping increases the total structure weight of the first stage by about 8 per cent, sheet tolerance by 5 to 6 per cent.

The revised ranges resulting from these changes are shown in Fig. 6 for one and two-motor missiles. They were estimated from the ranges given in Fig. 4 by using a correction factor based on the percentage change of the ratio propellant weight to first stage weight[3].

Comparing Fig. 4 and 6 shows that the heavier structures and motors cause a loss of range varying from 10 to 15 per cent.

4 Study of Three Particular Designs

As a result of the previous studies (para. 3) it was evident that the operational requirement for the range to be greater than 2,000 n. miles should be met with a missile having two motors only. The weight of the head was still undecided, the most pessimistic figure being 7,000 lb, the optimistic one 4,000 lb.

Further studies, therefore, concentrated on such a missile carrying heads of maximum and minimum weight. Different shapes of missile were included - conical, cylindrical with different fineness ratios, etc. - and the investigation covered the design in rather more detail. Cylindrical missiles present an easier transportation problem than the conical missiles with their wide bases and may be somewhat easier to construct. These studies are still incomplete but three particular missiles are described below. They are provided with skirts to give roughly neutral stability although it has been shown in the meantime that skirts are probably inefficient on cylindrical missiles and fins are preferred.

The take-off acceleration was chosen at 0.3g (see para. 3).

The following three designs have been investigated:

(a) A conical first stage carrying a low drag head of 7,000 lb weight.

(b) A cylindrical first stage of 10 feet diameter carrying a high drag head of 7,000 lb weight.

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* Since this Note was written it has been learned that this figure includes a thrust mount and bearing, items which have been allowed for separately. Elimination of this duplication will reduce the missile weight by about 400 lb. The performance figures will still apply if this is treated as additional residual fuel.

(c) A cylindrical first stage of 9 feet diameter carrying a medium drag head of 4,100 lb weight.

The basic design was the same as those of the earlier missiles, i.e. tanks of stainless steel of 65 tons/sq in. ultimate strength after welding, a safety factor of 1.5 to the ultimate, and 40 lb/sq in. pressurisation.

Weight increases resulting from a mean sheet tolerance of 0.003 in. and from overlap joints were included; so were some additional minor details such as cable ducts, anti-swirl baffles, etc.

The missiles are shown in Fig. 7, their weight breakdown is given in Table IV.

The following is a short description of the missiles with emphasis on their differences.

4.1 The Conical Missile (Fig. 7A)

The principal features agree with the conical missiles treated so far, except for the positioning of the guidance equipment which was moved from the stabilizing skirt to a special chamber ahead of the tank. This was considered to be desirable in order to keep this equipment away from the vibrations of the rocket motors and to make it more accessible to servicing without interference from the engine compartment. In this particular design the guidance chamber was assumed to be pressurised to 20 lb/sq in., sufficient to support the inertia load of the head.

As on the previous missiles the motor thrust was taken up by a set of intersecting beams, forming a web construction inside the base tank dome. The web construction was welded to a strong ring supporting the tank wall.

4.2 The Cylindrical Missile (Fig. 7B and C)

In these two designs the guidance chamber was not pressurised. The missile wall, extending along the length of the guidance chamber, was stabilized by a deeply corrugated light alloy stiffening structure.

An improved motor support has been designed consisting of one independent tripod for each motor, made of tubular steel, and bolted to a strong ring of tank diameter size. A short stabilized extension of the tank wall takes the thrust to the tanks.

The stabilizing skirt of corrugated aluminium alloy was bolted to the strong ring so as to be detachable for transport.

4.3 Weight Comparison

The total structure weight of the conical missile is 5,638 lb. This is 367 lb or 7 per cent more than the structure weight of a similar missile of paragraph 3.4 and Table III. The weight addition is made up of guidance chamber, cable duct, etc., minus a reduction in tank weight due to a smaller fuel volume.

It is not possible to give a straightforward comparison of weight increase for the two cylindrical missiles as no missiles of this configuration have been estimated before. Their guidance chambers are about double the weight of the guidance chamber of the conical missile because their diameters are bigger and they are mechanically stabilized. It can be assumed that the weight penalty for the separate, unpressurised guidance chamber above is between 8 and 10 per cent.

Comparing the two cylindrical missiles (Table IV B and C) one notes that in spite of the different tank diameters and fineness ratios, their total structure weights differ by less than one per cent. It should be noted that because of the lighter head the 9 foot diameter missile has a larger tank and carries more propellant than the 10 foot missile.

The total structure weight of the conical missile is roughly 4 per cent higher than the total structure weight of the cylindrical missile, which is mainly due to the conical tank and to the larger diameter of the skirt.

The structure weight factor τ of Fig. 2 has gone up from 0.024, for a butt-welded two-motor missile of 0.3g initial acceleration and 7,000 lb head weight, to about 0.029 for the same type of missile but including overlaps, tolerances, separate guidance chamber, etc., thereby reducing the weight efficiency by about 20 per cent.

4.4 Range Estimations

To obtain a more accurate assessment of the influence of drag on missile range, a step by step calculation has been applied for the powered part of the missile trajectory consisting of:

(a) a vertical climb of 20 seconds duration; then

(b) a constant rate of turn of the missile, chosen so as to keep the angle of incidence small; then

(c) along a constant thrust angle until reaching an acceleration of 10g; then

(d) at a constant acceleration of 10g until cut-off point, with 1 per cent residual propellants.

After cut-off the missile separates and the head coasts along a ballistic trajectory until it reaches the targets.

The calculated ranges are:

(a) Conical Low Drag Missile

With a head weight of 7,000 lb the range is 1,840 n. miles. Compared with a missile of similar design but revised structure weight as described in paragraph 3.4 (Fig. 6 and Table III) the loss of range is 90 n. miles; about 45 per cent of this is due to increase in structure weight, and about 55 per cent to increase in drag.

(b) Cylindrical High Drag Missile (10 feet diameter)

With a head weight of 7,000 lb the range is 1,720 n. miles. Compared with the same missile of paragraph 3.4, the loss of range is 210 n. miles, whereof approximately 7 per cent is due to higher weight and 93 per cent to higher drag.

(c) Cylindrical Medium Drag Missile (9 feet diameter)

With a head weight of 4,100 lb the range is 2,170 n. miles. Compared with the corresponding missile of paragraph 3.4, carrying a 4,100 lb head, the reduction in range is 140 n. miles. No comparable weight figures of previous design for a missile of this head weight are available, therefore, an actual ratio of range losses through weight and drag cannot be given, but it can safely be assumed that the larger part of the reduction in range is due to increase of drag.

It will be seen that the cylindrical missiles with blunt nose cones have very high drag which accounts for a serious loss of range. The re-entry stage is not expected to exceed 5 feet in diameter so that the guidance chamber and the top part of the tank can be tapered at a low angle to reduce the drag. These cone-cylinder bodies are being investigated with a view to establishing the best compromise between drag and structure weight.

5 Conclusions

It is difficult to pick out direct comparisons from a study of this nature where considerations other than structural design have altered the field of investigation as it progressed. Some general points emerge although further work needs to be done on many variables.

(a) These studies have confirmed us in our opinion that it is feasible to make a structure which weighs less than 3 per cent of the all-up-weight.

(b) The importance of the effect of structural weight changes on range performance is stressed, though it should be remembered that the weights of all other components carried to fuel cut-off are just as important in this respect.

As an illustration, on a typical two-motored missile a 7 per cent increase in the dry weight of the first stage (about 700-800 lb) causes about 100 nautical mile loss in range.

(c) The effect of including sheet tolerance in the structural weight is appreciable; 0.001 inch on the mean thickness of the steel sheets is equivalent to $\frac{1}{2}$ per cent decrease in range. This point also infers that it is desirable to make sheets of exact sizes to avoid overweight due to standard gauges.

(d) All the designs are made for constant gauge material in the tank section, and the stress is only critical at one point; there is clearly a saving to be made by tapering the sheet thickness to take the local loading conditions, but the extent of this is not evaluated in this Note.

(e) The lightest tank structure considered is made of high tensile material with simple butt-joints. Overlapping joints are estimated to increase the weight of a typical tank structure by about 8 per cent, equivalent to a loss in range of roughly 2.5 per cent.

(f) The performance curves indicate that, using a given motor and a specified re-entry head, a low initial acceleration gives longer range. The maximum range occurs when this take-off acceleration is about 0.1g; this was felt to be undesirably low on other grounds and an arbitrary figure of 0.3g was taken as the practical minimum.

(g) Cylindrical missiles have much the same structural weight as conical ones and have similar performances (it should be noted that cylindrical missiles are at present favoured by reason of easier transportability and to some extent easier manufacture).

(h) The high drag shapes of the cylindrical missiles considered, with their blunt nose cone angles to accommodate the high drag type of re-entry head, are causing considerable drag losses, up to 190 n. miles in range. It is clearly desirable to make the lowest drag shape to take the re-entry head (which should not exceed 5 feet in diameter) without adversely affecting the structural weight.

In conclusion the studies have shown that even with more pessimistic assumptions than before, and certainly more pessimistic than necessary in some respects, a missile powered with two N.A.A. S.3 motors (now quoted at 135,000 lb thrust) and with a head or re-entry stage weight of about 4,000 lb, should have a range of about 2,200 nautical miles.

6 Further Work

Design studies are continuing; of particular interest are:

(a) The use of fins instead of a skirt for stabilizing the missile. Recent aerodynamic studies suggest that fins are more efficient than a skirt on a cylindrical missile.

(b) The study of cylindrical missiles of larger diameters. The present limit of 10 feet was set on grounds of transportation, and it is desired to examine briefly the performance of larger diameter missiles. It is expected that the drag of such larger diameter missiles will be a serious obstacle.

(c) The reduction of the drag of cylindrical missiles by shaping of the front end, for example, by tapering the guidance chamber and part of the upper tank.

(d) The possibility of reducing the tank stabilizing pressure. Recent information shows that the turbo pumps can operate satisfactorily at lower pressures than were originally considered. At lower pressures, the bending moments on the missile will have greater importance. These bending moments will depend on the trajectory and on the control system employed. A clearer picture of the position here is being sought.

REFERENCES

No.	Author	Title, etc.
1	N.E. Wild	Preliminary Study of the Structure Weight of Long Range Ballistic Missiles. R.A.E. T.N. GW 333. August 1954.
2	D.G. King-Hele and Miss D.M. Gilmore	Long Range Surface-to-Surface Rocket Missiles: Properties of Ballistic Trajectories in Vacuo. R.A.E. Tech. Note No. GW 305. March 1954.
3	D.G. King-Hele and Miss D.M. Gilmore	The Effect of Various Design Parameters on the Weight of Long Range Surface-to-Surface Ballistic Rocket Missiles. Part 1. One and Two-Stage Missiles with One Stage of Propulsion. R.A.E. Tech. Note No. GW 332. August 1954.
4	The Members of the MRBM Mission	Report on Medium and Long Range Ballistic Missile Development in the U.S.A. R.A.E. Tech. Note No. GW 348. December 1954.

Attached:

Tables I to IV
Drgs. GW/P/6868 to 6874
Detachable Abstract Cards

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Table I - Selection of Weight Breakdowns for Conical Missiles with Different Initial Accelerations

Sheets butt jointed. No overlaps
Nominal thickness of material

Tank pressurisation 40 p.s.i.

U.T.S. after welding. Steel 65 tons/sq in.
" (riveted) light alloy 17 tons/sq in.

Initial Acceleration	0.2g			0.0g			0.1g			0.5g			0.0g		
Number of Main Motors	1			1			2			3			3		
	ins	lb	lb	ins	lb	lb	ins	lb	lb	ins	lb	lb	ins	lb	lb
Tanks															
Wall	0.032	1093		0.036	1263		0.040	2253		0.048	2607		0.056	3959	
Front dome	0.032	23		0.032	58		0.032	58		0.032	58		0.032	58	
Partition dome	0.032	91		0.032	136		0.032	179		0.032	247		0.032	350	
Base dome				0.040	225		0.056	462		0.064	686		0.072	1102	
Webs		390			176			466			747			1040	
Strong ring					149			260			252			304	
Joint rings		65			70			77			80			85	
Formers	0.032	102		0.036	162		0.036	245		0.036	276		0.036	367	
Pipes		168			154			212			194			204	
			1932			2393			4212			5147			7469
Skirt															
*Wall	0.056	253		0.064	287		0.064	483		0.064	503		0.064	694	
*Formers	0.080	48		0.080	52		0.080	70		0.080	74		0.080	120	
Motor support		60			120			240			360			360	
Fixing		210			120			135			150			150	
			571			579			928			1087			1324
TOTAL STRUCTURE WEIGHT			2503			2972			5140			6234			8793
Main motor(s)		1260			1260			2520			3780			3780	
Auxiliary motor(s)		100			100			200			300			300	
Guidance		500			500			500			500			500	
Control		400			400			600			800			800	
			2260			2260			3280			5380			5380
Liquid oxygen		59224			81828			131379			164899			251884	
Kerosene or Ethyl Alcohol		42013/			49940			93201/			80487			122943	
			101237			121768			224580			245386			374827
TOTAL FIRST STAGE			106000			127000			233000			257000			389000
Head			5000			5000			7000			7000			7000
A.U.W.			111000			132000			240000			264000			396000
Consumable fuel			100225			120550			222334			242932			371079
Cut-off weight			9775			11450			17666			21068			24921
τ		0.0241			0.0238			0.0224			0.0248			0.0229	
ξ		0.946			0.949			0.954			0.945			0.954	

* Light Alloy
/ Ethyl-Alcohol

$$\tau = \frac{\text{Weight of Structure}}{\text{Weight of Fuel + Structure}} \qquad \xi = \frac{\text{Weight of Consumable Fuel}}{\text{Total Weight of First Stage}}$$

TABLE II

Weight Breakdowns for Conical Missiles with 0.3g Initial Acceleration

Tank pressurisation 40 p.s.i.

Sheets butt jointed. No overlaps
Nominal thickness of material

U.T.S. after welding Steel 65 tons/sq in.
" (riveted) Light Alloy 17 tons/sq in.

Missile	A			B			C		
Number of Main Motors		1			2			3	
	ins	lb	lb	ins	lb	lb	ins	lb	lb
Tanks									
Wall	0.032	928		0.040	1840		0.048	2866	
Front dome	0.032	58		0.032	58		0.032	58	
Partition dome	0.032	104		0.032	197		0.032	280	
Base dome	0.036	149		0.056	474		0.064	782	
Webs		197			498			888	
Strong ring		92			269			302	
Formers	0.032	120		0.036	233		0.036	310	
Joint rings		70			75			80	
Pipes		130			168			188	
			1848			3812			5754
Skirt									
*Wall	0.064	220		0.064	409		0.064	565	
*Formers	0.080	45		0.080	68		0.080	106	
Motor support		120			240			360	
Fixings		120			135			150	
			505			852			1181
TOTAL STRUCTURE WEIGHT			2353			4664			6935
Main motors		1260			2520			3780	
Auxiliary motors		100			200			300	
Guidance		500			500			500	
Control		400			600			800	
			2260			3820			5380
Liquid oxygen		60430			126062			191722	
Kerosene		29495			61531			93578	
			89925			187593			285300
TOTAL FIRST STAGE			94538			196077			297615
Head			7000			7000			7000
A.U.W.			101538			203077			304615
Consumable fuel			89026			185717			282447
Cut-off weight			12512			17360			22168
τ			0.0255			0.0243			0.0237
ξ			0.0942			0.0947			0.949

$$\tau = \frac{\text{Weight of Structure}}{\text{Weight of Fuel + Structure}}$$

$$\xi = \frac{\text{Weight of Consumable Fuel}}{\text{Total Weight of First Stage}}$$

Missile shapes and sizes are shown in Fig. 3

* Light Alloy

TABLE III

The Effect of Overlaps and Sheet Tolerances on the Weight of some Conical Missiles

Number of Motors	Initial Acceleration	Head Weight lb	Structure Weight without Overlaps & Tolerances	Weight Increase Through Overlaps		Weight Increase Through Tolerances		Structure Weight with Overlaps & Tolerances	Weight Increase through heavier motor	Total Weight Increase
				lb	%	lb	%			
1	Zero	5000	2972	236	7.94	168	5.65	3376	600	1004
1	9.2g	5000	2503	194	7.75	141	6.03	2817	600	914
1	0.3g	7000	2353	174	7.39	138	5.86	2665	600	912
2	0.1g	7000	5140	411	8.00	262	5.10	5813	1200	1873
2	0.3g	7000	4664	370	7.93	237	5.08	5271	1200	1807

Table IV – Weight Breakdowns for Three Particular 2-Motor Missiles with 0.3g Initial Acceleration

1½% allowance for sheet overlaps
+0.003" mean tolerance allowed on material thickness

Tank pressurisation 40 psi

U.T.S. of steel (after welding) 65 tons/sq in.
" of light alloy (riveted) 17 tons/sq in.

Missile Type	A Conical			B 10 ft diam. Cylindrical			C 9 ft diam. Cylindrical		
	ins	lb	lb	ins	lb	lb	ins	lb	lb
Guidance Chamber									
Wall	0.040	141		0.036	301		0.032	228	
*++Stiffening		-		0.048	194		0.048	183	
Rings		27			63			67	
Separation gear		100			100			100	
Fixings		50	318		50	708		50	628
Tanks									
Wall	0.040	2189		0.036	1984		0.032	2069	
Front dome	0.032	70		0.032	195		0.032	159	
Partition dome	0.032	238		0.032	195		0.032	159	
Base dome	0.056	552		0.040	240		0.040	195	
+ Webs		492			-			-	
+ Strong ring		269			-			-	
Welding ring		42			36			22	
Formers	0.032	226		0.032	214		0.032	269	
Anti-swirl baffles		60	4138		46	2910		40	2913
Pipes									
Liquid oxygen feed		168			258			333	
Kerosene feed		5			6			6	
Liquid oxygen pressurising		21			20			26	
Kerosene pressurising		7			10			14	
Fixing		50	251		50	344		50	429
Electric Cable Duct									
Channel		25			23			35	
Clips, overlaps, etc.		10	35		10	33		12	47
Motor Support									
Wall extension		-			109			106	
Stiffening		-			135			115	
Thrust ring		-			197			120	
Framework		100			286			300	
Thrust pivot plates		45			45			45	
Actuator mounting		50			50			50	
Fixings		100	295		100	922		100	836
Skirt									
*Wall	0.064	465		0.064	417		0.064	440	
*Formers	0.080	71		0.080	62		0.080	62	
Fixings		65	601		50	529		50	552
TOTAL STRUCTURE WEIGHT			5638			5446			5405
Main motors		3720			3720			3720	
Auxiliary motors		200			200			200	
Guidance		500			500			500	
Control		600	5020		600	5020		600	5020
Liquid oxygen		124602			124731			126707	
Kerosene		60817	185419		60880	185611		61845	188552
TOTAL FIRST STAGE			196077			196077			198977
Head			7000			7000			4100
A.U.W.			203077			203077			203077
Consumable fuel			183565			183755			186666
Cut-off weight			19512			19322			16411
τ		0.0295			0.0285			0.0279	
ξ		0.936			0.937			0.938	

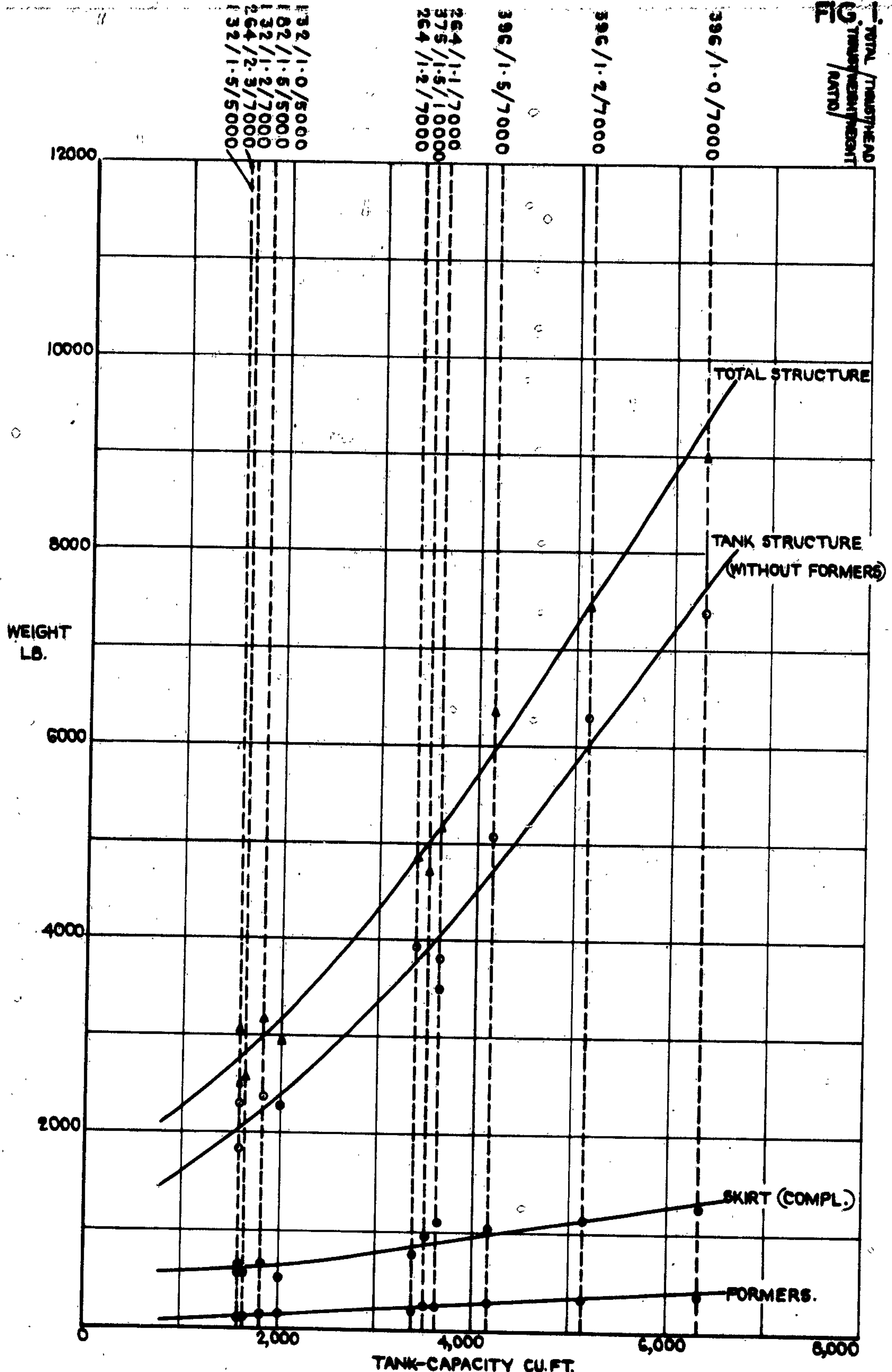
$$\tau = \frac{\text{Weight of Structure}}{\text{Weight of Fuel + Structure}} \qquad \xi = \frac{\text{Weight of Consumable Fuel}}{\text{Total Weight of First Stage}}$$

* Light Alloy

++ No stiffening required for conical missile as chamber assumed to be pressurised

+ Webs and strong ring although included in tank structure, are main components of motor support on conical missile

Missile shapes and sizes are shown in Fig. 7



MATERIAL: TANK: STEEL 65 T/IN² ULT. WELDING STRENGTH.
SKIRT: LIGHT ALLOY 17 T/IN² ULT. STRENGTH.
BUTT JOINTS, NO OVERLAP, NOMINAL SHEET THICKNESSES

FIG. 1. STRUCTURE WEIGHT VERSUS TANK-CAPACITY.

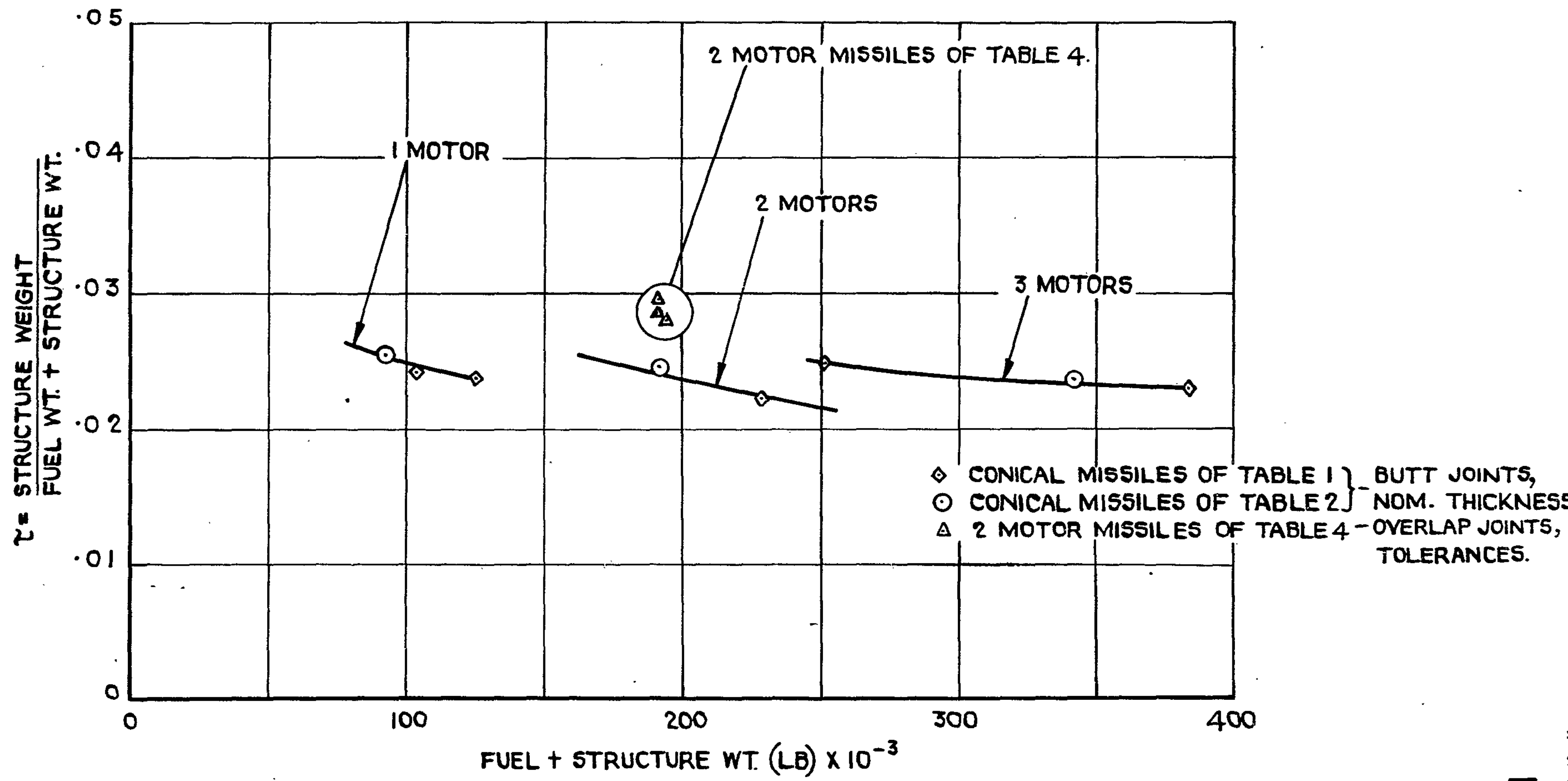
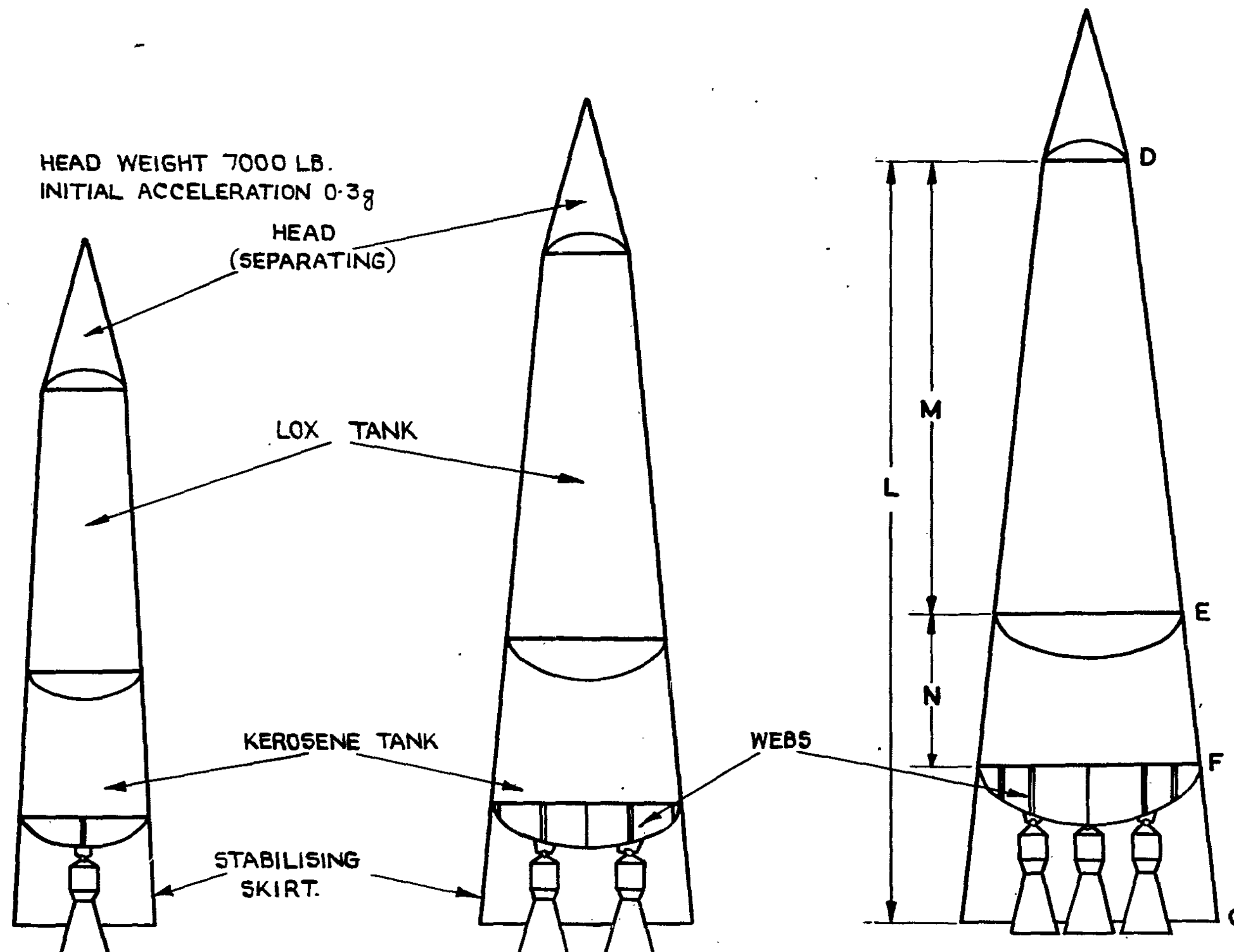


FIG. 2. STRUCTURE WEIGHT FACTORS.



DIMENSION IN FEET

	A	B	C
DIAMETERS			
D	6	6	6
E	8·0	11·1	13·2
F	9·1	13·0	15·6
G	9·8	14·7	18·0
LENGTHS			
L	37·7	47·4	54·0
M	20·0	27·5	32·4
N	10·2	10·4	10·8

FIG. 3. CONICAL MISSILES WITH ONE, TWO AND THREE, STANDARD MOTORS.

FIG. 4.

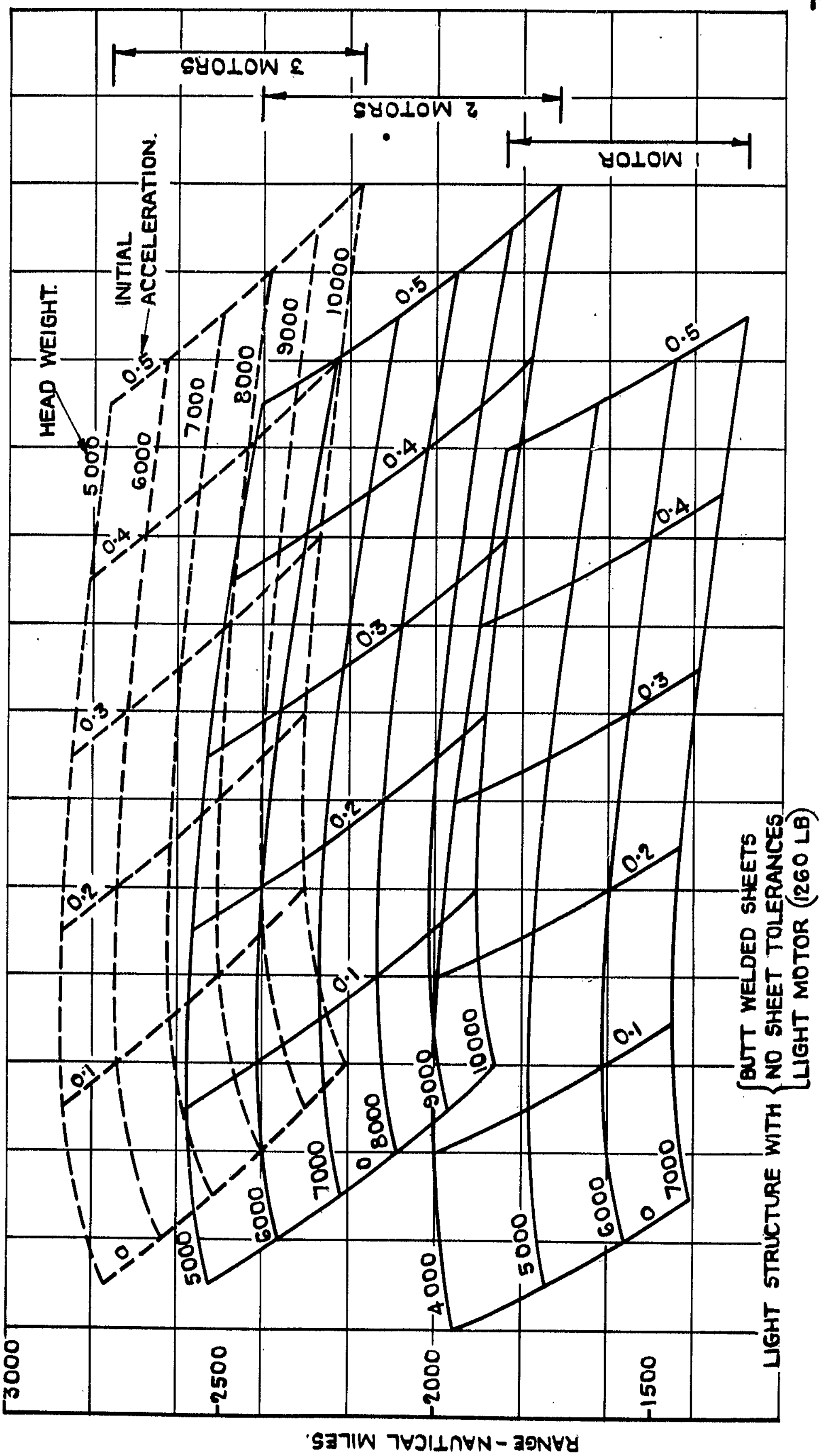


FIG. 4. RANGE PLOTS FOR 1, 2 AND 3-MOTOR MISSILES. (LIGHT STRUCTURE).

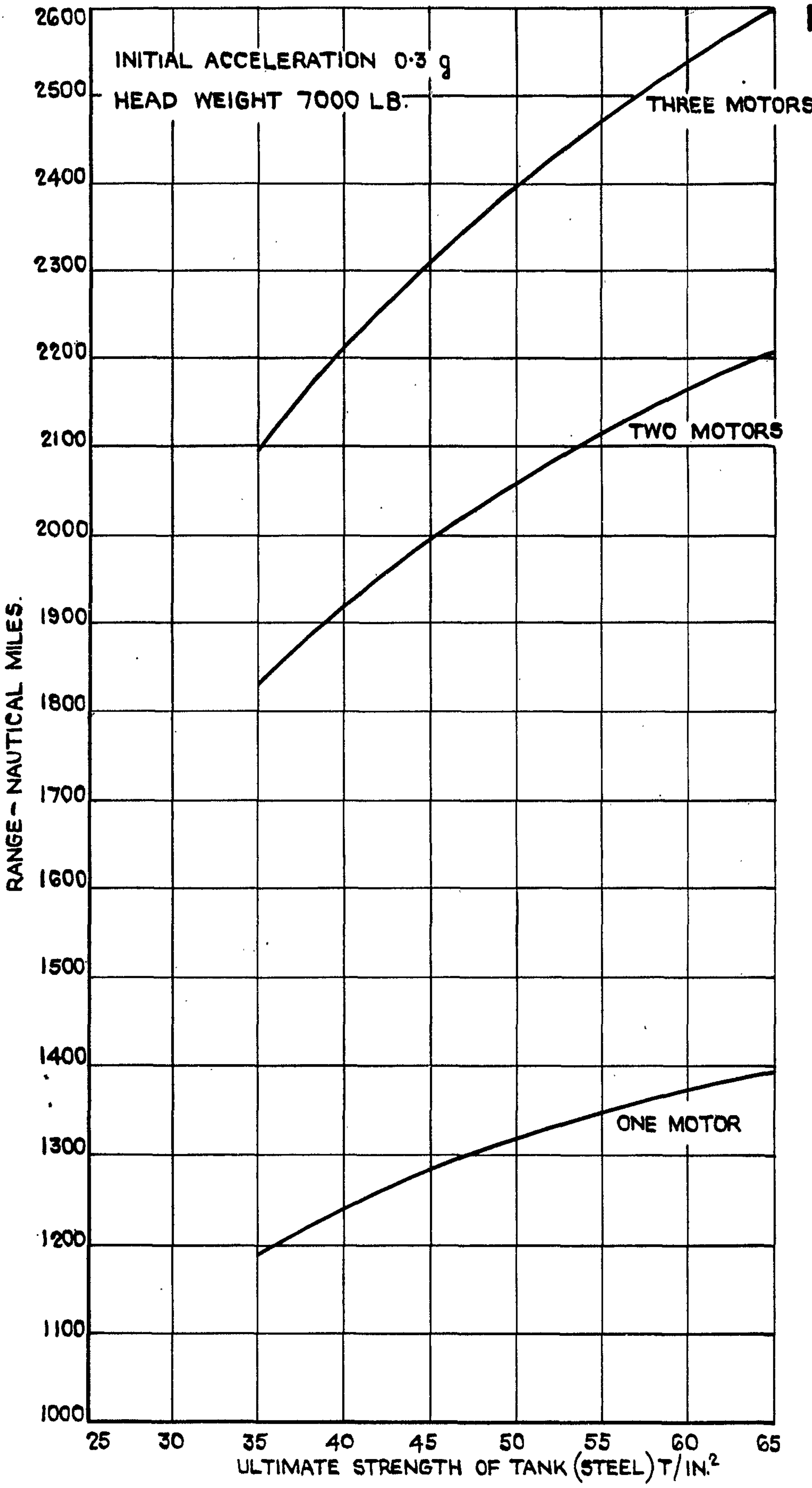


FIG. 5. INFLUENCE OF STRENGTH OF TANK MATERIAL ON MISSILE PERFORMANCE.

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FIG. 6.

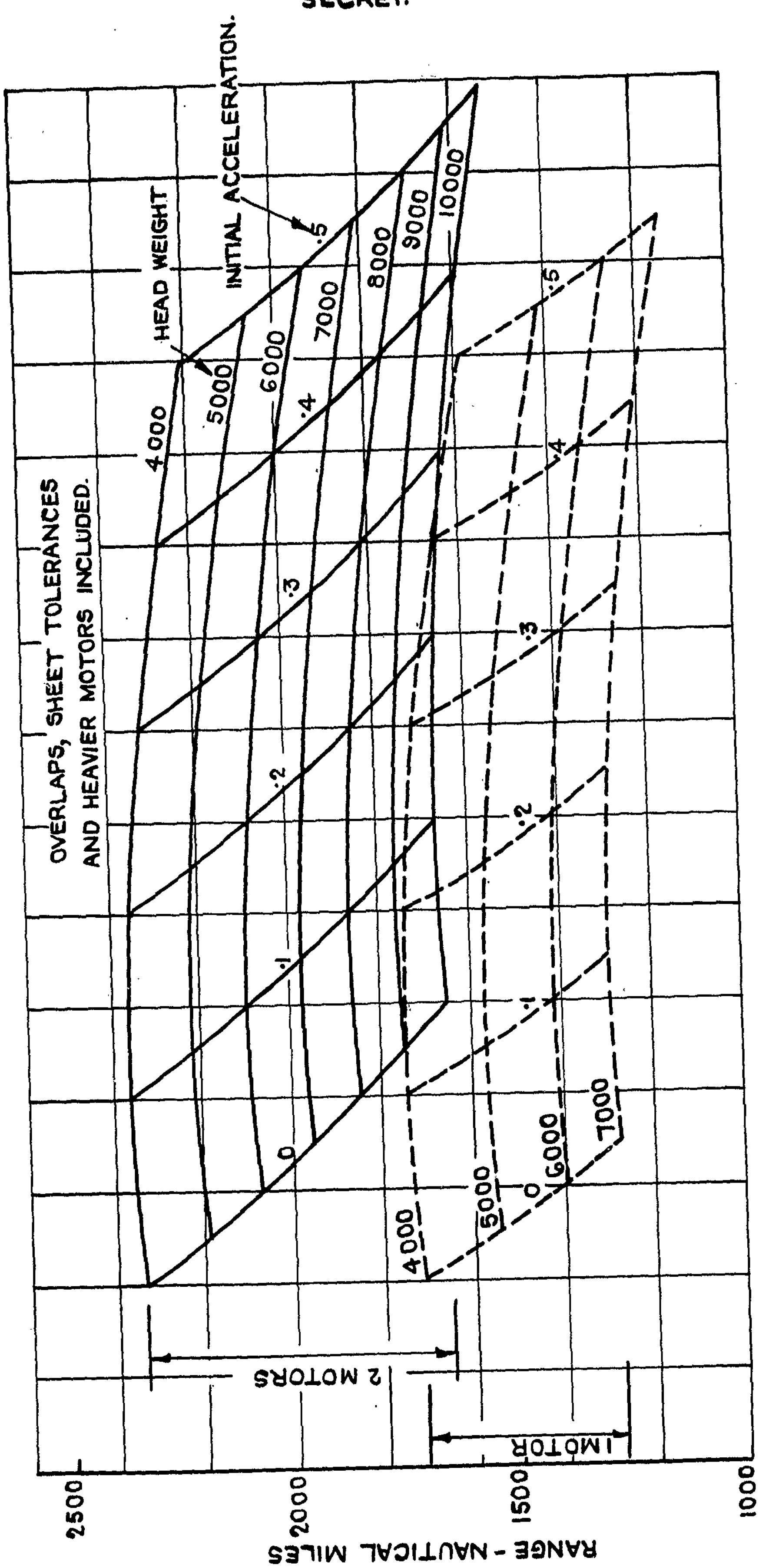

FIG. 6. REVISED RANGE PLOTS FOR 1 AND 2—MOTOR MISSILES.

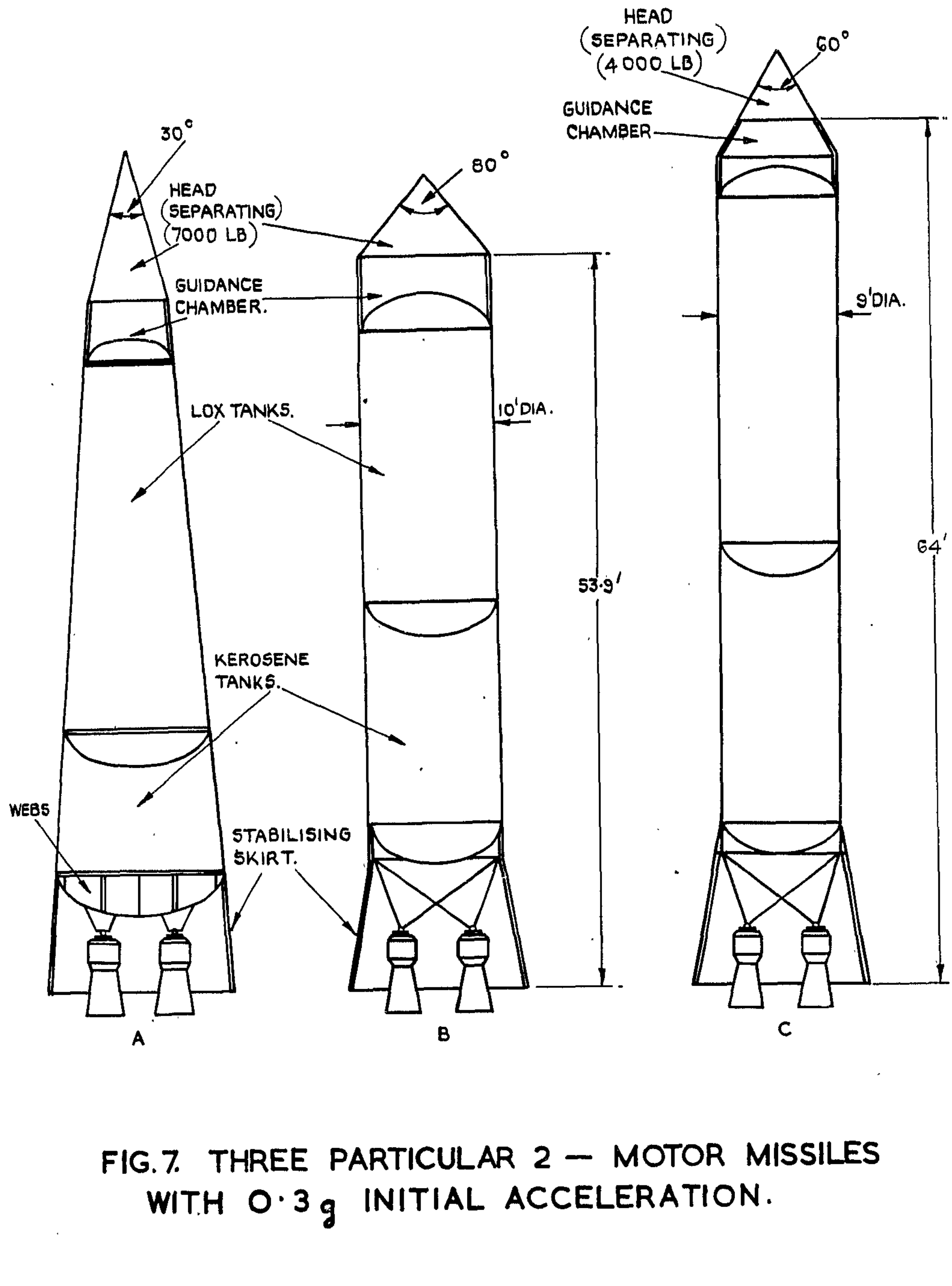

FIG. 7. THREE PARTICULAR 2 — MOTOR MISSILES WITH 0·3 g INITIAL ACCELERATION.

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Wild, N.E. and Ulrich, H.R.

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The note discusses the structural weight of ballistic missiles having one propulsion stage and a re-entry stage separated from the main stage at the end of propulsion. The effects on weight (and hence range) of re-entry stage weight, shape (conical and cone-cylinders only), take-off acceleration, ultimate tensile strength of tank sheet, type of welded joints (butt, overlap and butt strap) and tolerance on sheet thickness are studied. Configurations using one, two or three rocket motors of 132,000 lbs thrust are also studied.

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The note indicates the further work which will be required to complete the study.

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